Characterization of a low current-high voltage air arc discharge at high pressure

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Electrical characterisation of a plasma system composed of a low current – high voltage arc discharge plasma torch and a resonant converter power supply has been performed as a function of hydrodynamic variables (gas flow rate and pressure). It has been observed that these parameters influence strongly the arc discharge characteristics (arc length, mean voltage, stability). The electrical analysis shows the existence of three plasma device functioning modes, which are clearly identified by the ambient temperature Reynolds number. According to the Reynolds number, these modes correspond to laminar, transition and turbulent regimes. In addition, pressurization (from 1 to 3.5 bars) puts to advantage the stability of the discharge and the dissipated electrical power.

1. Introduction

Stability and plasma homogeneity are usually demanded in main plasma devices applied to chemical issues. Prior to the optimisation of any plasma device, the characterisation of the performances overall plasma system (plasma reactor together with the power supply) is needed.

This paper presents the influence of hydro-dynamics variables such as gas flow rate and pressure on the electrical performance of a plasma system composed of a low current – high voltage arc discharge plasma torch and a resonant converter power supply. It makes possible to identify the different functioning regimes of the plasma device.

This work follows a series of previous studies [1], [2] carried out on similar configurations. Here we focused on the influence of mean current and air flow rate at atmospheric pressure, which led us to identify three electric regimes: streamer, glidarc and quasi-continuous.

2. Experimental set-up

The plasma device is mainly composed of a compact non-thermal arc plasma torch, a post-discharge reactor and a power supply (see figure 1).

Plasma torch geometry is very similar to those encountered in classical high current DC plasma devices. An electrical discharge is established between a central and an annular electrode (tip/cylinder configuration). A high voltage insulating ceramic material separates the two concentric electrodes. A high velocity gas mixture injected radially at the vicinity of the central electrode blows down a low current/high voltage arc discharge generated between the electrodes. The shortest distance between electrodes is 3 mm. Four thermocouples are placed along the reactor. The closest thermocouple to the plasma torch is 60 mm downstream the cylindrical electrode in order to avoid any interference with the electrical discharge.

System can be fed in either by air only (which is the case in this study) or a mixture of air, water and hydrocarbon (case of reforming). Air flow rate and absolute working pressure vary in the range from 0.2 to 5 Nm^3/h and from 1 to 3.5 bars, respectively. Currents and voltages involved for the discharge are in the order of magnitude of 0.5 A and 2 kV respectively (mean power around 1 kW).

The power supply is based on a resonant converter technology and it was specially developed for the application. A 15 kV maximum voltage can be achieved while current is limited to 660 mA. Contrary to high voltage transformers currently used for similar applications, this power supply provides continuous control of the arc. Electrical signals are analyzed by a 2 channels digital oscilloscope (HP 54615 B). Voltage measurement is performed using a 1:1000 probe (Elditest, GE3830) while discharge current measurement is carried out with a hall effect current probe (PR 30: LEM).

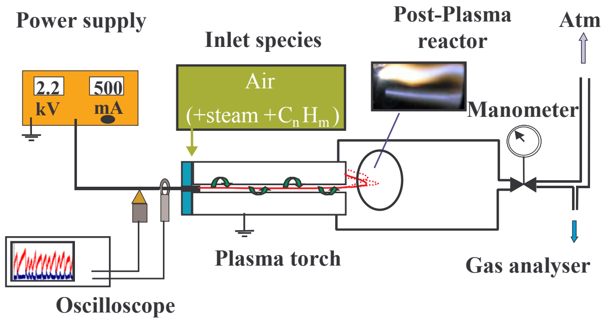

Figure 1. Scheme of the experimental set-up

3. Results

3.1. Quasi-continuous regime

Previous studies [1], [2] in a similar configuration provided on the influence of mean current and air flow rate at atmospheric pressure have identified three main regimes: streamer, glidarc and quasi-continuous.

Figure 2 presents the principle of a quasi-continuous discharge. Contrary to the gliding arc regime where the arc is confined inside the electrode pipe, the arc spot gets in this case stabilized at the output of the annular electrode in a highly turbulent zone characterized by important gas recirculation, that induce electrical oscillations. Length named L_A is the nozzle length (a constant) while L_B could vary when changing flow rate or/and pressure. The arc itself does not re-ignite, as it can be seen from the oscillogram on figure 3.

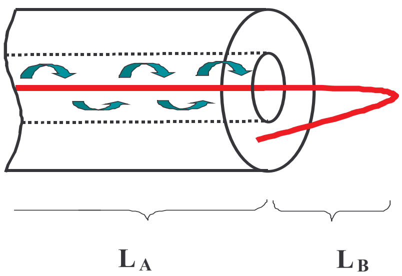

Figure 2. Quasi-continuous discharge

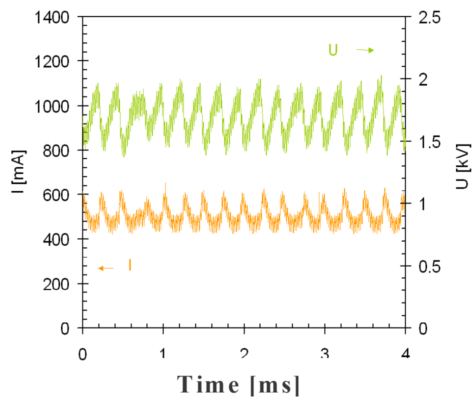

Figure 3. Oscillogram of quasi-continuous arc

3.2. Discharge regimes

Ambient temperature Reynolds number is defined as $Q/\Box D\mu_0$, where Q is the air flow rate, D is the nozzle diameter and μ_0 is the dynamic viscosity at ambient temperature (300 K). Figure 4 sketched the minimum, mean, and maximum voltage and its standard deviation versus the ambient temperature. The change in the slope of the values indicates the critical Reynolds numbers.

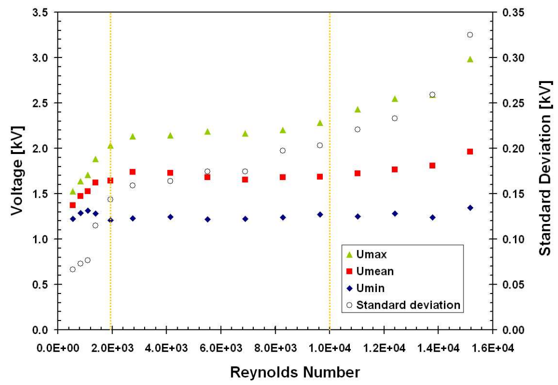

Figure 4. Voltage versus Reynolds number

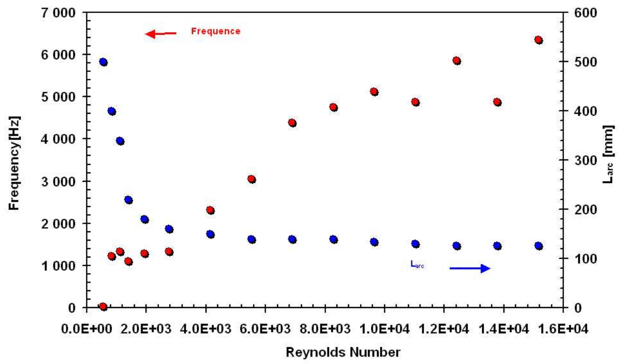

Figure 5. Arc frequency and arc length versus Reynolds number

They correspond to around 2000 and 10 000, separating laminar, transitional and turbulent sub-regimes.

Figure 5 shows the characteristic frequencies of voltage data and the arc length. The first were obtained by FFT analysis. The arc length was calculated as $L_A + L_B$ and L_B was measured experimentally from photographs.

Laminar regime is characterized by slightly growing voltages, low frequency and important arc length; transition regime by a plateau regarding voltage values and increasing frequencies; the turbulent regime by increasing voltages and bigger slope of frequencies.

3.3. Influence of working pressure

By increasing residence time, pressure has significant interests in reactive mixtures (higher performances). From this perspective, study of the influence of the pressure on the arc behavior has been studied. Pressure has been modified in the range from 1 to 3.5 bars. As the pressure increases, mean voltage raised up and thus the dissipated power reaches higher values (current being held constant by the power source). See figure 6.

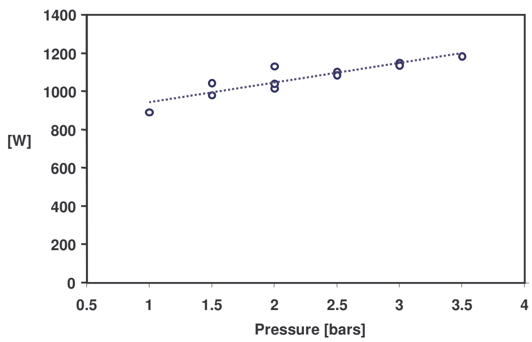

Figure 6. Influence of the pressure on dissipated power through the arc discharge

Furthermore, arc length increases (see figure 7) with the pressure while its frequency gets lower. This might be due to the decreasing velocity field.

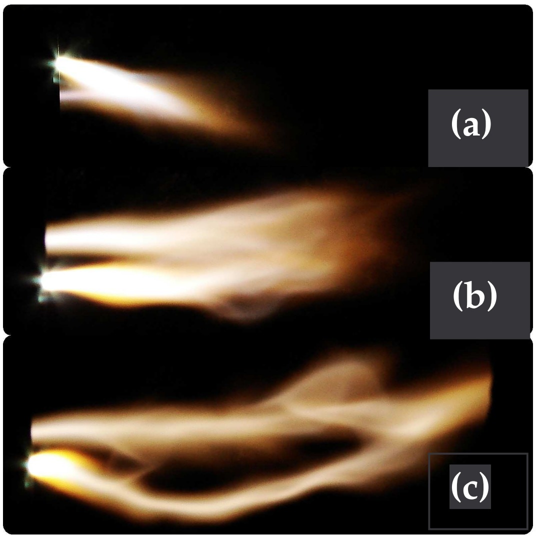

Figure 7. Plasma discharge at nozzle exit.
(a) 1 bar, (b) 2.5 bars, (c) 3.5 bars

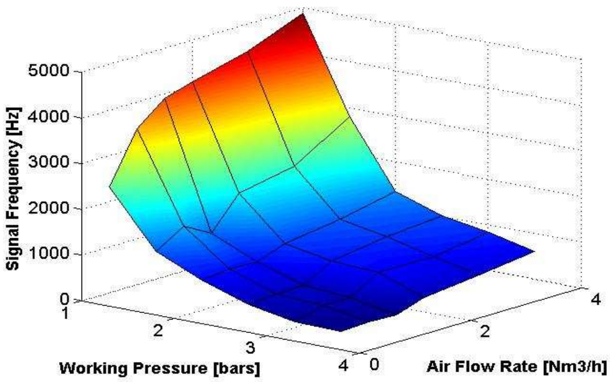

Figure 8. Influence of pressure and air flow rate on instabilities frequency.

At last, frequency of the instabilities significantly decreases with increasing pressure. Figure 8 illustrates the influence of pressure and air flow rate on instabilities frequency on a 3D plot. The figure shows that pressure has greater effect on instabilities frequency than air flow rate.

4. Conclusions

Characterization of the system has been performed and allowed us to identify main arc parameters as a function of the flow rate and the working pressure.

Depending on the Reynolds number, arc discharge shows either low voltage, good stability and important length or high voltage (and thus dissipated power) but less stability and frequency. High-pressure conditions (up to 3.5 bars) have shown a favourable impact on the discharge: more dissipated power (as the mean voltage grows), longer arc and less important instabilities (highly decreasing frequency).

Best conditions depend of the desired effect: in the perspective of efficient chemical conversion, high injected power (and thus high pressure) is desirable but compromise should be made considering arc stability (i.e. low Reynolds number gives pretty good stability but low dissipated power)

Future work would concern effect on radical concentration (via optical emission spectroscopy) and running of similar study in the case of reacting mixture.

Acknowledgements

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